



# Performance Investigation of a Full-Scale Hybrid Composite Bull Gear

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May 18<sup>th</sup>, 2016 – AHS Forum 72



- **Motivation**
- **Past efforts**
- **Bull gear design**
- **Experimental setup**
- **Results**
- **Conclusions**
- **Future work**



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## Motivation



**ARL**

- **Several past government programs aimed at increasing rotorcraft power density**
- **Advanced rotorcraft configurations require the ability to change rotor speed, which requires additional drive components further increasing drive system weight**
- **No suitable replacement for steel in durable high-stress contacts**
- **Hybrid composite gears are being investigated to replace the structural portion of a steel gear with lightweight composite material**

## Small-Scale Proof-of-Concept

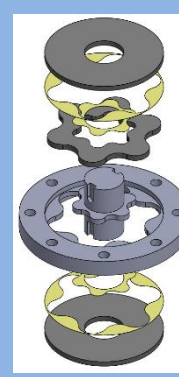
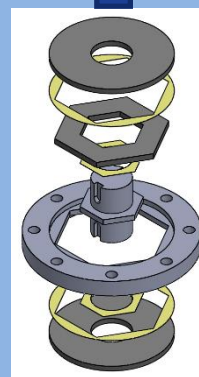
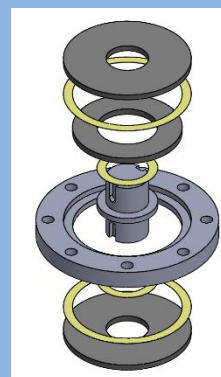


Endurance testing of 3.5" pitch diameter coupon gears



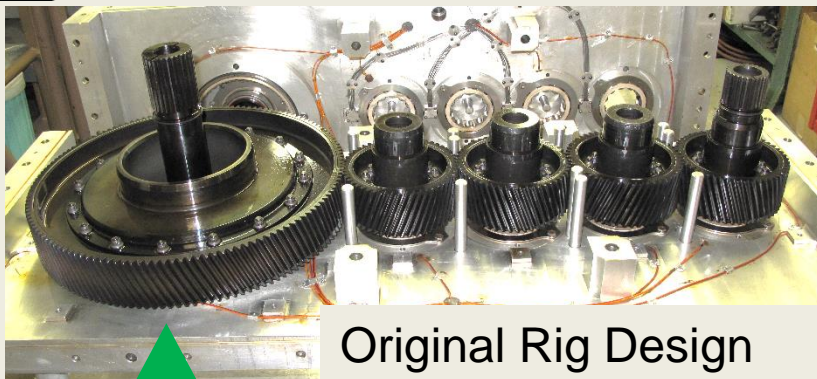
Static torque tests on coupon level gears

## Full-Scale Bull Gear



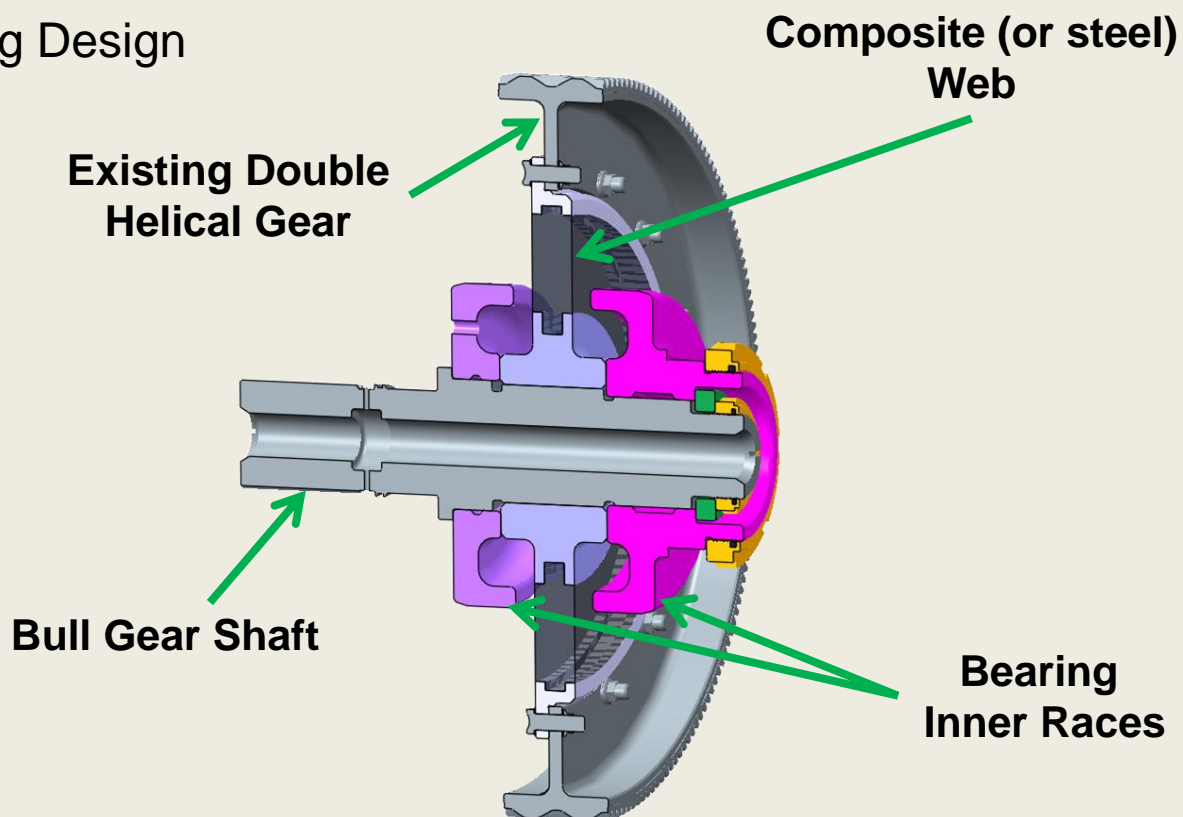
Mechanical interlock testing



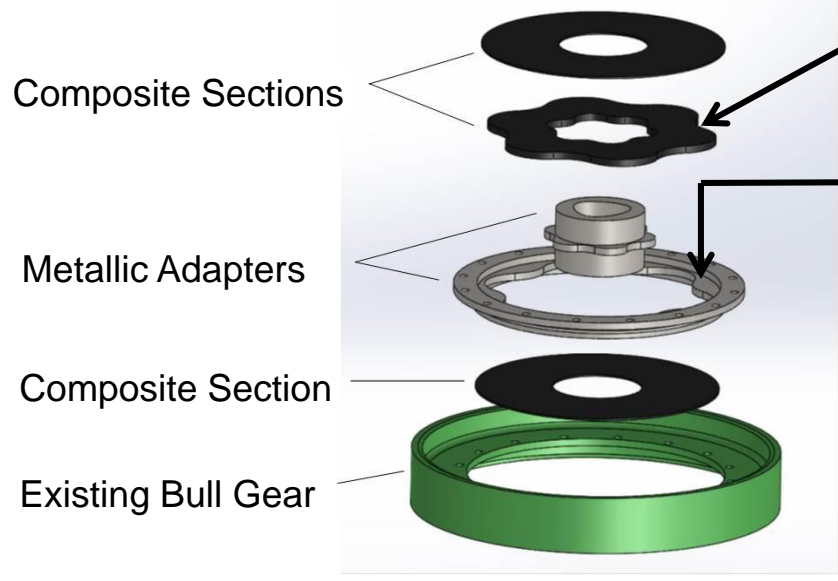


Original Rig Design

Modular hybrid bull gear design allows for several hybrid web designs to be evaluated with minimal additional cost.



## Exploded View of Hybrid Web

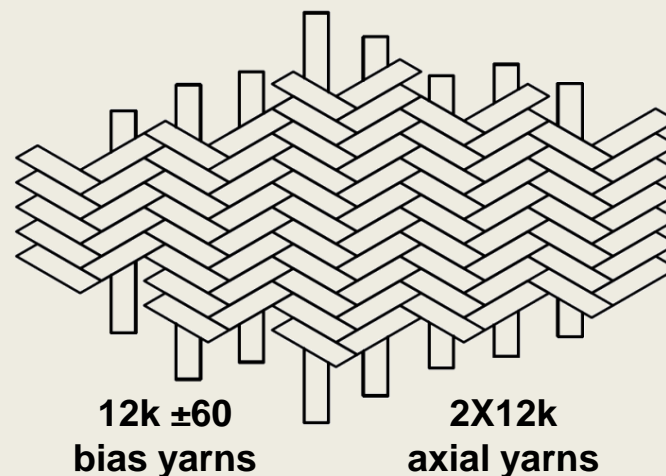


## Torque Transfer Mechanisms

Mechanical interlock

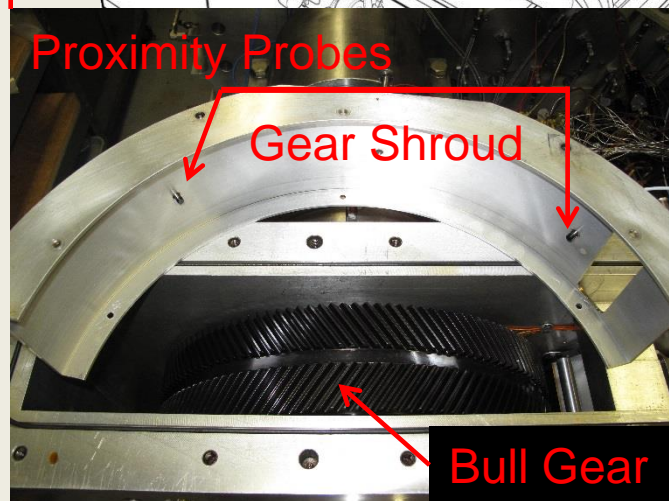
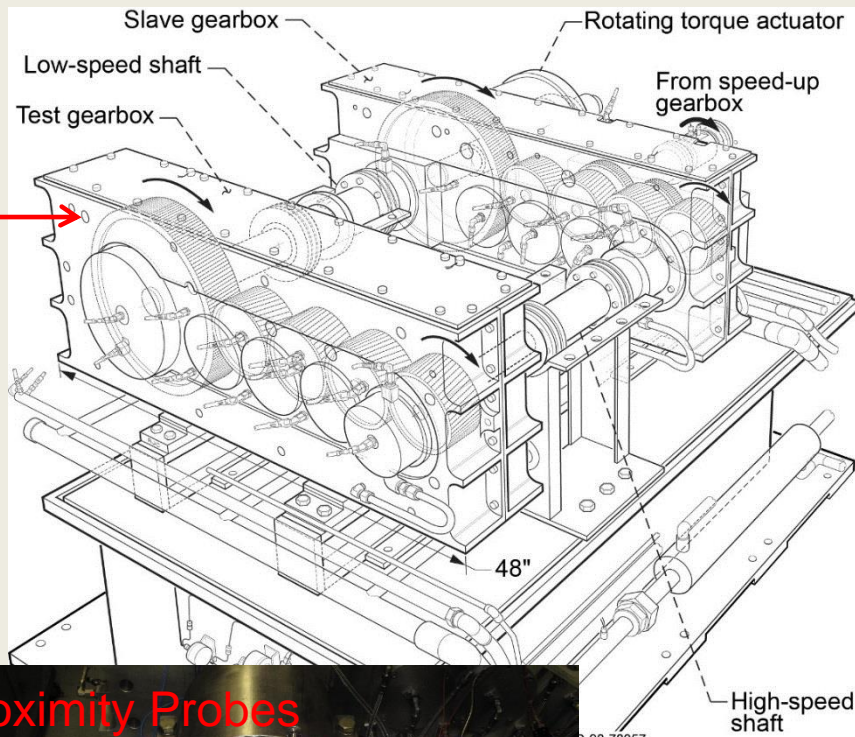
Adhesive bond at axial  
steel/composite interface  
(Cytec MTA-241 film adhesive)

## Triaxial Braid Architecture



## Braided composite information

- T-700 SC carbon fibers
- Prepreg 0°, +/- 60° braided architecture
- Equal fiber volume in all directions
- Tencate TC-250 resin with 56% fiber volume



## NASA Glenn Research Center High-Speed Helical Gear Rig

Rig capable of running at aerospace conditions (5,000 HP)

- Input Pinion: 15,000 RPM at 21,000 in-lbs
- Bull Gear: 5475 RPM at 58,400 in-lbs
- Up to 250°F oil inlet temperature

## Instrumentation

- Axial and radial vibration monitoring at bull gear bearing housing
- Proximity sensors for monitoring bull gear orbit



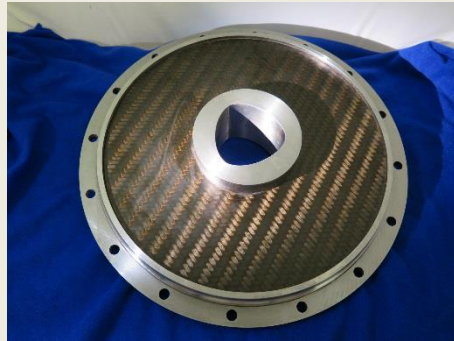
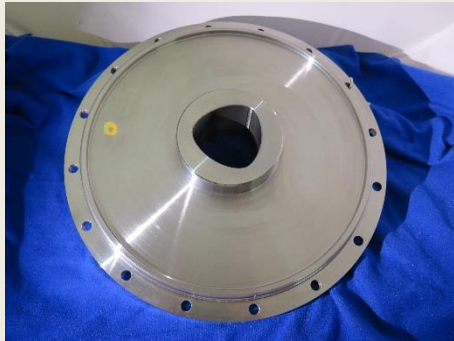


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# Test Matrix



**ARL**



- Tests were run with an oil inlet temperature of 120°F
- Tests were run according to the test matrix
- Vibration level and orbit size were monitored during testing

Run Condition	Shaft Speed (RPM)	Torque in-lb (N-m)		Power hp (kW)	
1	900	5,000	(560)	71	(53)
2	900	10,000	(1,130)	143	(106)
3	900	15,000	(1,690)	214	(160)
4	1,800	5,000	(560)	143	(106)
5	1,800	10,000	(1,130)	286	(213)
6	1,800	15,000	(1,690)	428	(319)
7	2,700	5,000	(560)	214	(160)
8	2,700	10,000	(1,130)	428	(319)
9	2,700	15,000	(1,690)	643	(479)
10	3,600	15,000	(1,690)	857	(639)
11	3,600	19,300	(2,180)	1,102	(822)
12	4,500	19,300	(2,180)	1,378	(1,028)
13	4,500	38,600	(4,360)	2,756	(2,055)
14	4,500	58,400	(6,600)	4,170	(3,109)
15	5,400	19,300	(2,180)	1,654	(1,233)
16	5,400	38,600	(4,360)	3,307	(2,466)
17	5,400	58,400	(6,600)	5,004	(3,731)

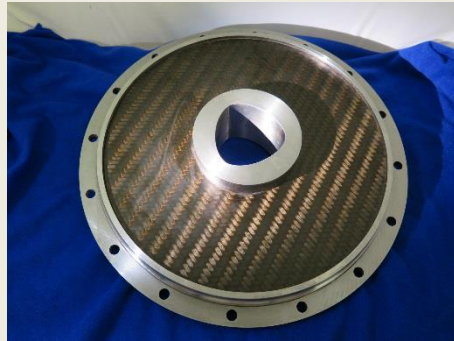
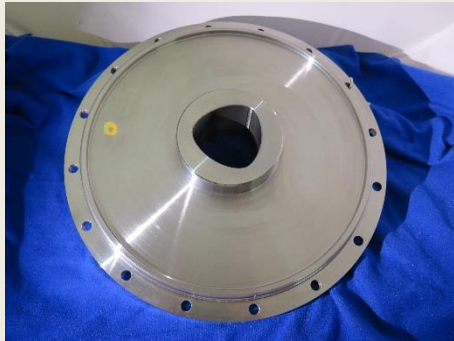
Note: Tabulated horsepower values in the paper are incorrect!





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# Test Matrix



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- **Hybrid bull gear tests were limited to 40% the static torque capacity of the web, eliminating conditions 14 and 17.**

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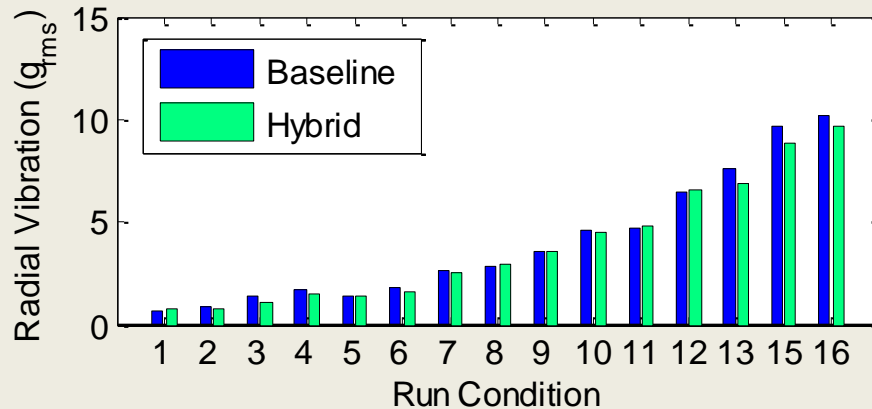
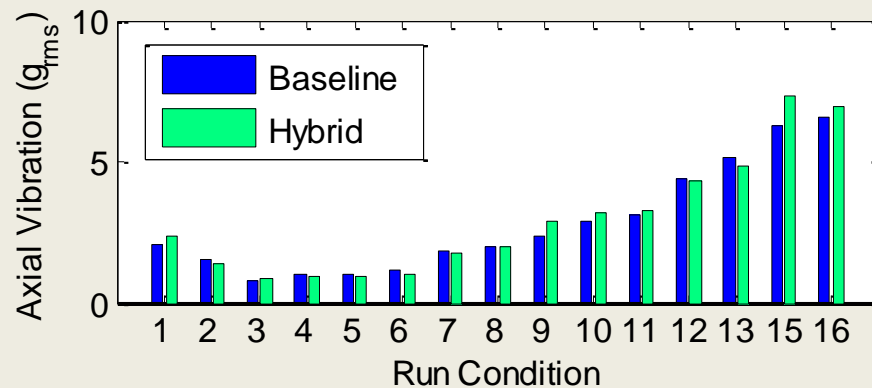
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# Results - Vibration



**ARL**

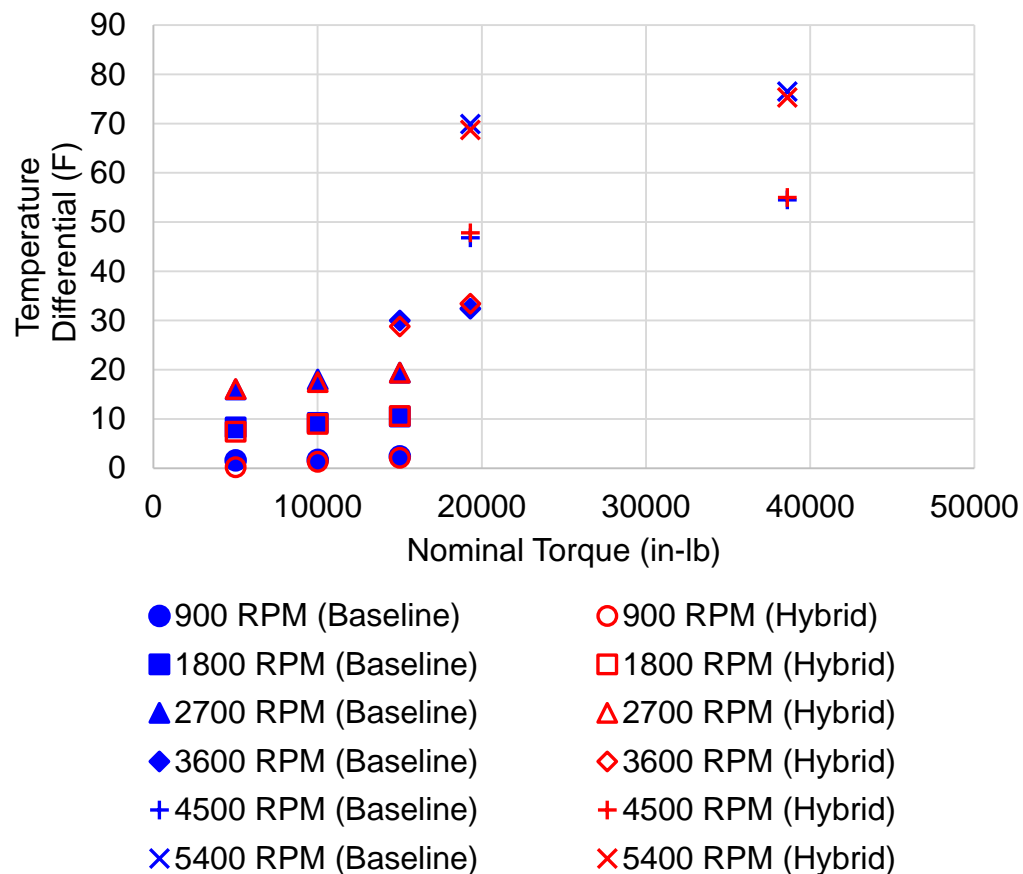
## Averaged Vibration Level



Run Condition	Shaft Speed (RPM)	Torque in-lb (N-m)
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14	4,500	58,400 (6,600)
15	5,400	19,300 (2,180)
16	5,400	38,600 (4,360)
17	5,400	58,400 (6,600)



$$T_{\text{diff}} = T_{\text{oil-outlet}} - T_{\text{oil-inlet}}$$



No increase in heat generation!





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# Results – Averaged Orbit

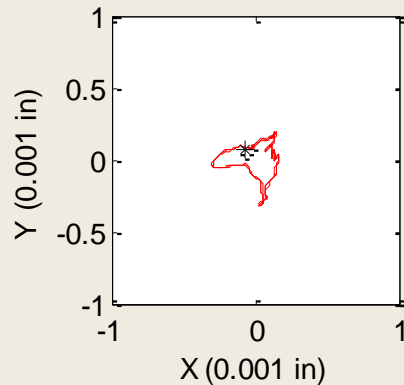


**ARL**

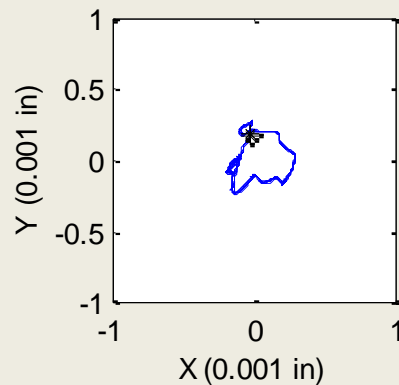
Run Condition 9:  
2700 RPM  
15,000 in-lbs

Run Condition 16:  
5,400 RPM  
38,600 in-lbs

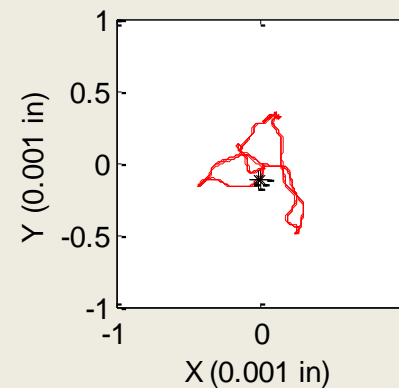
Baseline Gear



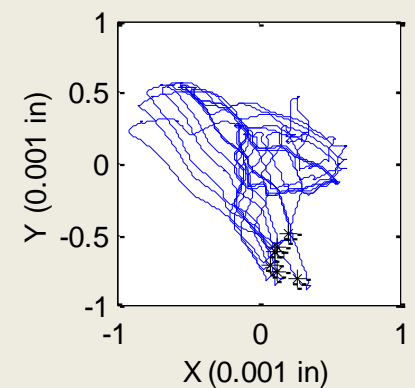
Hybrid Gear



Baseline Gear



Hybrid Gear



Hybrid gear orbit size starts to increase and change shape while at condition 16





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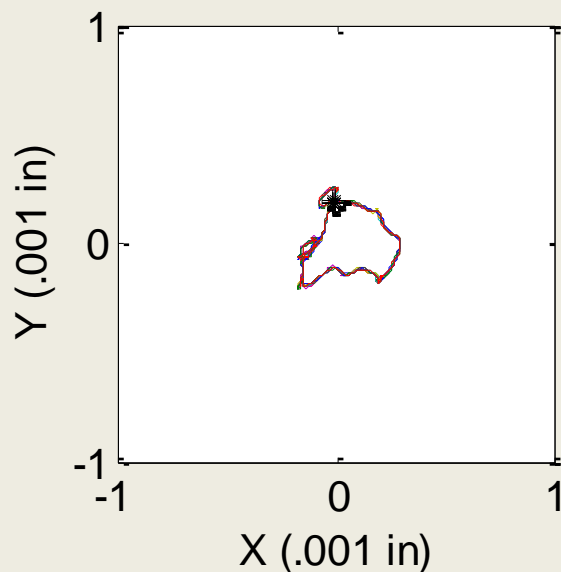
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# Results – Averaged Orbit

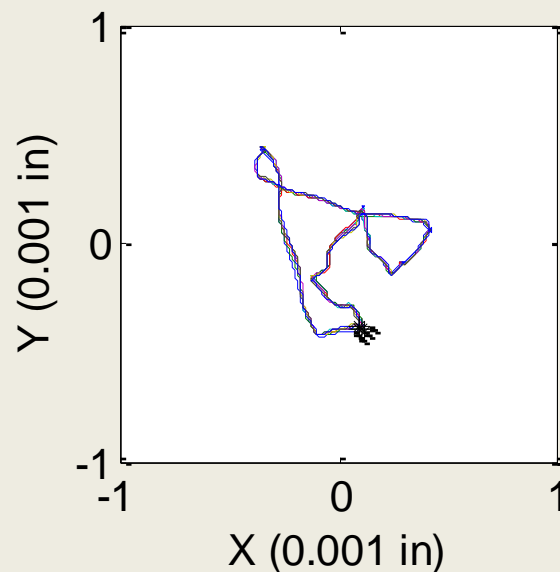


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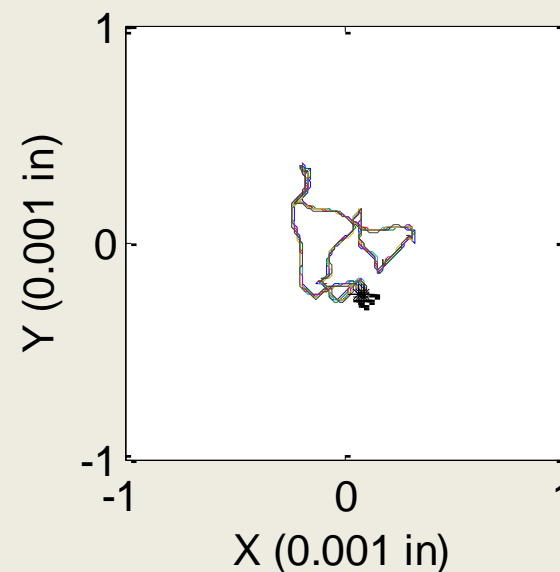
Testing day 1  
Condition 6 – Before  
max run condition



Testing day 1  
Condition 6 – After max  
run condition

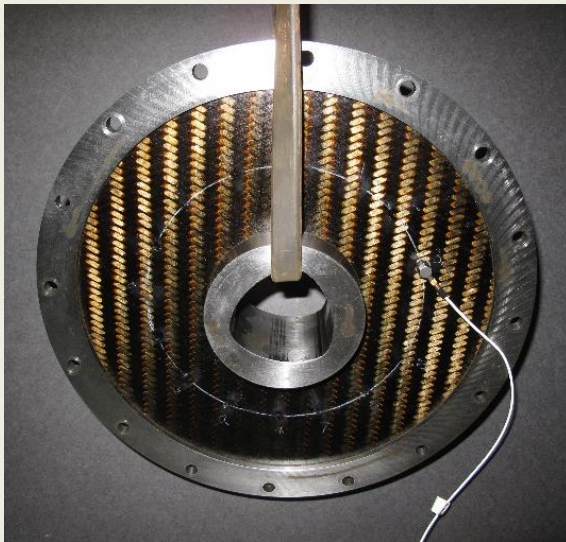


Testing day 2  
Condition 6

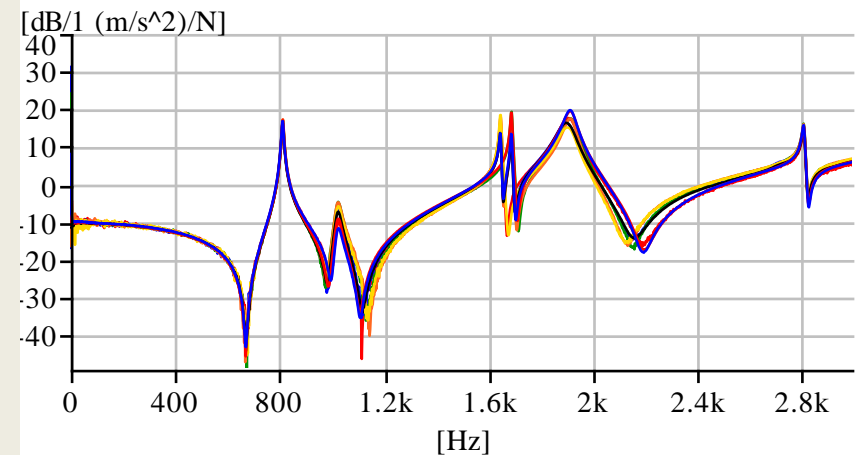


Change in shape after running at  
max 3300 HP condition

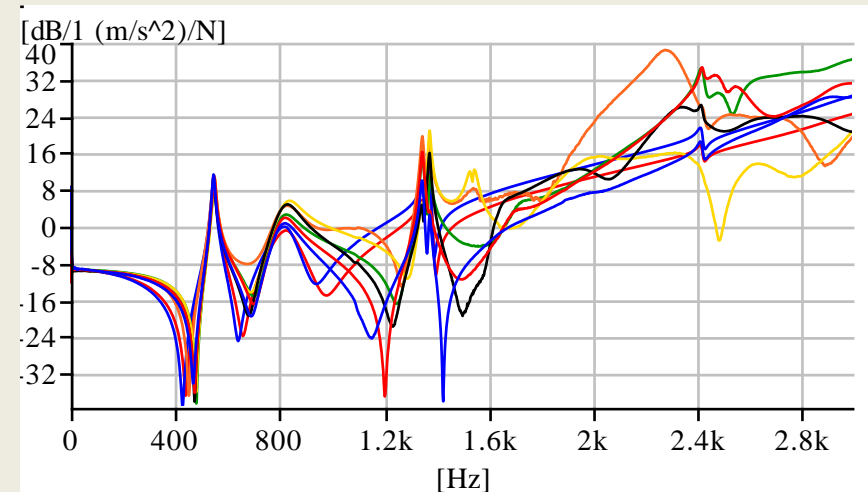
- **Ultrasonic testing was unsuccessful**
- **Alternatives**
  - **Scanning acoustic microscope**
  - **X-ray**
- **Instrumented hammer tests**



Driving Point FRF – Hybrid Web Tested



Driving Point FRF – Flawed Hybrid Web







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## Conclusions



**ARL**

- **Successfully tested a hybrid composite bull gear up to 3300 HP**
- **Increase orbit size at 3300 HP resulted in discontinuation of test**
  - **No loss of torque**
  - **Gear continued to perform at lower power conditions**
- **No increase in overall vibration level over baseline configuration**
- **Composite material has no apparent effect on operating temperature**
- **Instrumented hammer tests give good indication of inconsistencies in the composite material**



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## Future Work



**ARL**

- **Continue hybrid bull gear testing with 2 additional web designs**
  - **Reduced number of capture plies**
  - **Variable thickness web**
- **Investigate direct mating of composite to the polygon drive eliminating the inner metallic adapter**
- **Complete and validate finite element model of hybrid gear**
- **Investigate additional NDE techniques**
- **Hot oil material testing**
- **System level testing in a production gearbox**
- **Static loading under combined loads**

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RDECOM®****Questions?****ARL**

## Acknowledgements:

- **A&P Technology – NASA SBIR**
  - **Nathan Jessie**
  - **Mike Braley**

**A&P Technology**

## Past Publications:

PATENT: R. F. Handschuh and G. Roberts, “Hybrid Gear,” US 9,296,157 B1, 29-Mar-2016.

R. F. Handschuh, K. E. LaBerge, S. DeLuca, and R. Pelagalli, “Vibration and Operational Characteristics of a Composite-Steel (Hybrid) Gear,” NASA/TM-2014-216646; ARL-TR-6973, Cleveland, OH, Jun. 2014.

R. F. Handschuh, G. Roberts, R. Sinnamon, D. B. Stringer, B. D. Dykas, and L. Kohlman, “Hybrid Gear Preliminary Results—Application of Composites to Dynamic Mechanical Components,” in American Helicopter Society 68th Annual Forum, Fort Worth, Texas, 2012.